



Dinoflagellates in tropical estuarine waters from the Maraú River, Camamu Bay, northeastern Brazil

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Abstract

Dinoflagellates display great diversity in tropical regions and play an important role in the complex microbial food webs of marine and brackish environments. The goal of this study is to identify planktonic dinoflagellates and their distribution in the estuary of the Maraú River, Camamu Bay, state of Bahia, in a region with increasing use of shellfish farming. Samples were carried out monthly from August 2006 to July 2007 at four stations along the estuary. Plankton was sampled with a 20 µm mesh net. We identified 20 dinoflagellate species. The greatest species richness was observed in the genera *Protoperidinium* (five spp.), *Tripos* (four spp.), and *Prorocentrum* (three spp.). Based on literature, six species were classified as potentially harmful: *Akashiwo sanguinea*, *Dinophysis caudata*, *Gonyaulax spinifera*, *Prorocentrum micans*, *Scrippsiella cf. acuminata*, and *Tripos furca*. *Protoperidinium venustum* was recorded for the first time in coastal waters of Bahia.

Keywords

Brackish water, Dinophyta, distribution, potentially harmful species, taxonomy.

Academic editor: Luciane Fontana da Silva | Received 31 December 2018 | Accepted 2 October 2019 | Published 25 October 2019

Citation: Nunes CCS, Susini-Ribeiro SMM, Cavalcante KP (2019) Dinoflagellates in tropical estuarine waters from the Maraú River, Camamu Bay, northeastern Brazil. Check List 15 (5): 951–963. <https://doi.org/10.15560/15.5.951>

Introduction

Dinoflagellates are eukaryotic microorganisms, photosynthetic or not. They are assigned to the protist lineage Alveolata due to the presence of flattened vesicles under the plasma membrane, which can be empty or contain cellulose plates (Elbrächter and Hoppenrath 2009). Most species are characterized by the presence of two distinct flagella (transverse and longitudinal), which enable the typical whirling swimming of dinoflagellates (Taylor 1987). Dinoflagellates display high diversity in morphology, nutrition, and habitat.

There are c. 2500 extant species of dinoflagellates known so far (Elbrächter and Hoppenrath 2009). The

great diversity of dinoflagellates occurs in marine and brackish environments in which dinoflagellates constitutes one of the most important planktonic groups (Taylor 1987; Elbrächter and Hoppenrath 2009).

In Brazil, a recent compendium of algal flora showed that 420 species of dinoflagellates were recorded for Brazil, 384 of them occurred in brackish/marine environments (Menezes et al. 2015). Studies of plankton communities along the Brazilian coastal and estuarine regions have addressed aspects of the occurrence and ecology of planktonic dinoflagellates. However, the majority of these studies is concentrated in the southern and southeastern coastal regions (e.g. Rosa and

Buselato 1981; Kremer and Rosa 1983; Schmitt and Proen  a 2000; Islab  o 2008; Mello et al. 2010; Tavares et al. 2009; Alves et al. 2010; Haraguchi and Odebrecht 2010; Haraguchi 2010; Pedroso 2010; Islab  o and Odebrecht 2011; Mafra et al. 2014, 2015). On the northeast Brazilian coast, most of the studies were made in the state of Pernambuco and focused on the ecology of the phytoplankton community (e.g. Rosevel-da-Silva et al. 2005; Le  o et al. 2008; Tiburcio et al. 2011. Despite the importance of dinoflagellates, knowledge about their occurrence and distribution in northeastern Brazil remains scarce.

Camamu Bay is considered an area still only slightly affected by human activities due to the low population density (Hatje et al. 2008). However, the deployment of community-based sustainable aquaculture projects to increase income and diversify the economy have been intensifying in this region (Paix  o et al. 2011). In addition, increased tourism, as well as oil exploration on the adjacent continental shelf, could have a direct impact on this well-conserved area (Paix  o et al. 2011) and might also affect the diversity and abundance of local planktonic communities.

In previous research on the plankton community in Camamu Bay, 27 species of dinoflagellates were found (Affe 2012; Santana 2012), and five species were considered as potentially harmful: *Dinophysis acuminata* Clapar  de & Lachmann, *D. caudata* W.S. Kent, *Prorocentrum compressum* (Bailey) Dodge, *P. micans* Ehrenberg, and *P. sigmoides* B  hm (Affe 2012). These species are bloom-forming in many coastal regions of the world and cause several harmful effects to local biota and human populations, such as oxygen depletion due to bloom decay, massive kill of marine animals by mechanical damaging or clogging of gills, and the production of potent toxins, which contaminate fish and invertebrates and cause poisoning in humans by the consumption of seafood (Hallegraeff 2003). The presence of potentially harmful species certainly will pose a potential threat to public health and to the local economy. In this context, the goal of this study was to identify, illustrate, and describe the species of dinoflagellates present in the Mara   river estuary in Camamu Bay, and to expand the knowledge of the geographic distributions of the species found.

Methods

Camamu Bay is located between 13  40'12"S–038  55'48"W and 14  12'36"S–039  09'36"W at the narrowest portion of the Eastern Brazilian Coast (EBC), where the bifurcation of the South Equatorial Current takes place, giving rise to the formation of the two major Western Contour Currents: Brazil Current (BC) and Northern Brazil Current (NBC) (Amorim et al. 2011). The BC flows to the south and is dominated by a tropical oligotrophic surface water mass with high temperatures (27 °C in July–August to 30 °C in February–May) and salinity (36.7–37.0) (US Navy 1978; Castro and Miranda 1998). The EBC has a tropical climate, with the average annual

rainfall between 2400 and 2500 mm and average annual temperature of 25 °C (SEI 2014). Camamu Bay has a surface area of about 384 km² and receives waters of the Serinha  m, Igrapi  na, Pinar  , Soroj  , and Mara   rivers (Amorim et al. 2015). The Mara   river system is located in the southern part of Camamu Bay with a drainage area of 120 km². It is formed by the Mara   River and small tributary streams (Hatje et al. 2008). The average depth of this system is 6.2 m, with a maximum depth of 37 m in the main channel (Amorim 2005).

Salinity and depth were measured along the Mara   river estuary in order to establish sampling stations based on different portions of the estuary. Thus, plankton was collected monthly from August 2006 to July 2007 in four stations along the Marau estuary in three river regions, which were defined by their average salinity: station 1, 14  06'33"S, 039  02'48"W located upstream of the Marau estuary in the River Zone (RZ) characterized by low salinity (18.9 ± 2.9) and an average local depth of 7.1 m; stations 2 and 3, 14  04'52"S, 038  59'12"W and 13  57'24"S, 038  59'38"W, respectively) located in the Mixing Zone (MZ) with intermediate salinity (30.5 ± 5.3) and an average local depth of 4.1 m; and station 4, 13  54'56"S, 038  58'57"W) located downstream of the Marau river estuary at the entrance of Camamu Bay in the Coastal Zone (CZ) where the salinity is high (36.0 ± 2.8) and the average local depth is 8.8 m (Fig. 1).

Samples were collected using a 20 µm mesh plankton net, in horizontal sub-superficial circular trawls for 5 minutes. Forty-seven samples were stored in plastic bottles and immediately fixed with formalin solution neutralized with hexamethylenetetramine at 4% final concentration (Steidinger and Tangen 1997).

In the laboratory, aliquots of samples containing the dinoflagellates were stained with tripan blue solution to facilitate visualization of plate sutures (Steidinger and Tangen 1997). At least three fresh slides were analyzed in each of the 47 samples collected. The dinoflagellate specimens were measured and photographed under a Zeizz Axiostar Plus light microscope and Axiovert 40 CFL, which was equipped with Canon Power Shot G5 digital camera. For morphometric analysis, the following measurements were taken and abbreviations used: total length (TL), total width (TW), cell length (CL), cell width (CW), cell thickness (CT), epitheca length (EL), hypotheca length (HL), apical horn (AH), left antiapical horn (LAH), right antiapical horn (RAH), spine length (SL), anterior cingular list (ACL), posterior cingular list (PCL), left sulcal list (LSL), right sulcal list (RSL), distance between ribs 1 and 2 (R1-R2), distance between ribs 2 and 3 (R2-R3) and cingulum width (Cw).

Identification followed standard floras (e.g. Dodge 1975; Balech 1988; Steidinger and Tangen 1997) and recent reviews for each species. The classification system adopted for families and genera was based on Fensome et al. (1993), with alterations proposed for Protoperidiniaeae (Fensome et al. 1998) and Calciiodinellaceae (G  mez et al. 2011). Taxa were arranged by alphabetical order of

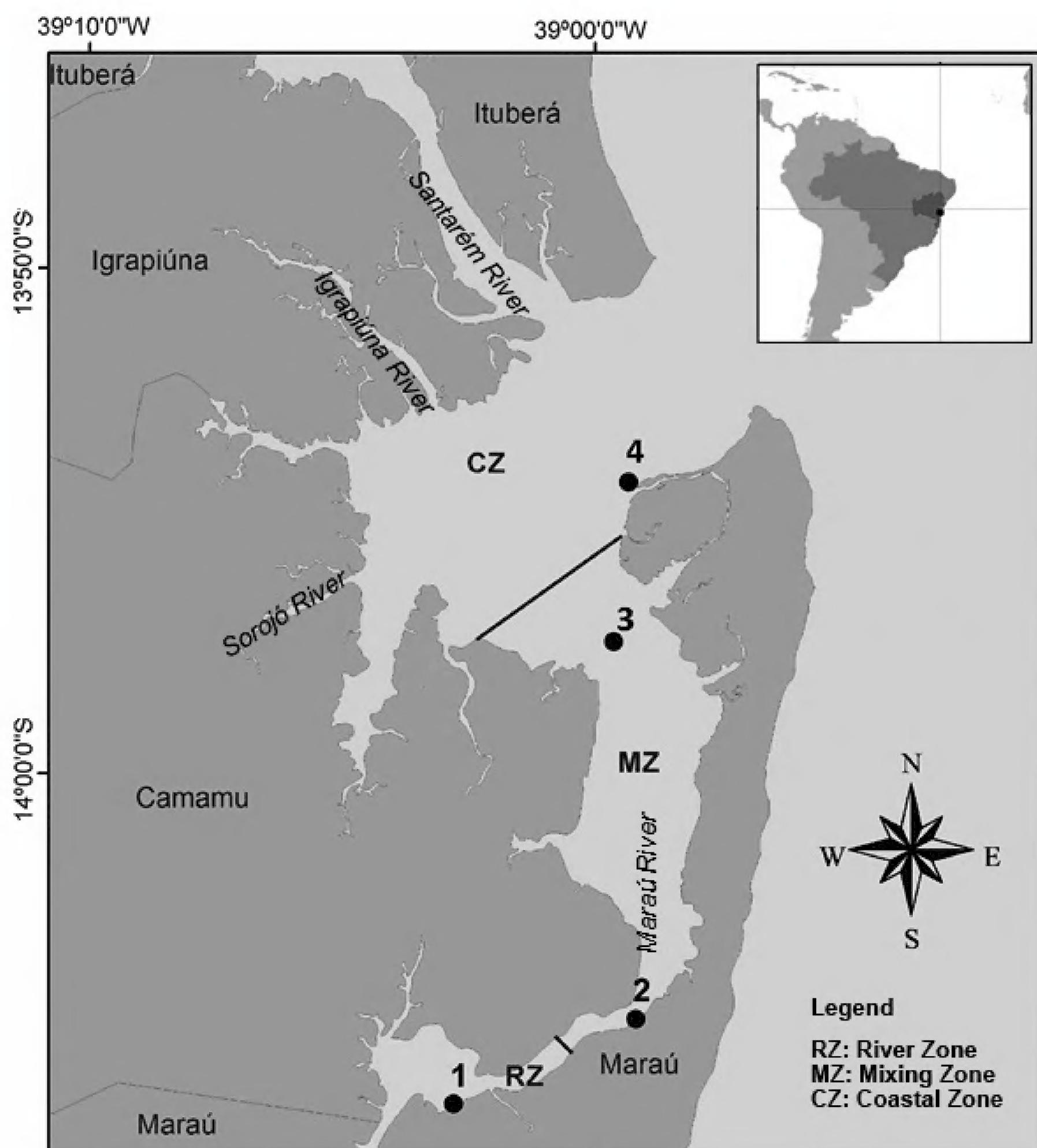


Figure 1. Study area with sampling points in the Maraú river estuary, Camamu Bay, Bahia. Black lines indicate transition among River Zone (RZ), Mixing Zone (MZ), and Coastal Zone (CZ).

families. The distribution of taxa in Brazilian states was based on the Brazilian Flora database (Flora do Brasil 2019), updated with references cited in the text. Samples were deposited in the Herbarium of the Estate University of Santa Cruz, Ilhéus, Bahia (HUESC 24039–24085).

Results

We identified 20 dinoflagellate taxa in the Maraú river estuary, distributed in eight families (Calcidinellaceae, Ceratiaceae, Dinophysiaceae, Gonyaulacaceae, Gymnodiniaceae, Prorocentraceae, Protoperidiniaceae, and Pyrocycladaceae) and 11 genera. Among them, *Protoperidinium* Bergh was the genus with the greatest number of

species (five), followed by *Tripos* Bory (four), and *Prorocentrum* Ehrenberg (three). The genera *Akashiwo* Hansen & Moestrup, *Amylax* Meunier, *Dinophysis* Ehrenberg, *Gonyaulax* Diesing, *Metadinophysis* Nie & Wang, *Ornithocercus* Stein, *Pyrophacus* Stein, and *Scrippsiella* Balech ex Loeblich III showed a single taxon each.

Family Calcidinellaceae Deflandre 1947

***Scrippsiella* cf. *acuminata* (Ehrenberg) Kretschmann, Elbrachter, Zinssmeister, Soehner, Kirsch, Kusber & Gottschling, 2015**

Figure 2A

Brazil, estuary of Maraú River: Mixing Zone Station 2: 14°04'52"S, 038°59'12"W, I.2007 (HUESC 24055).

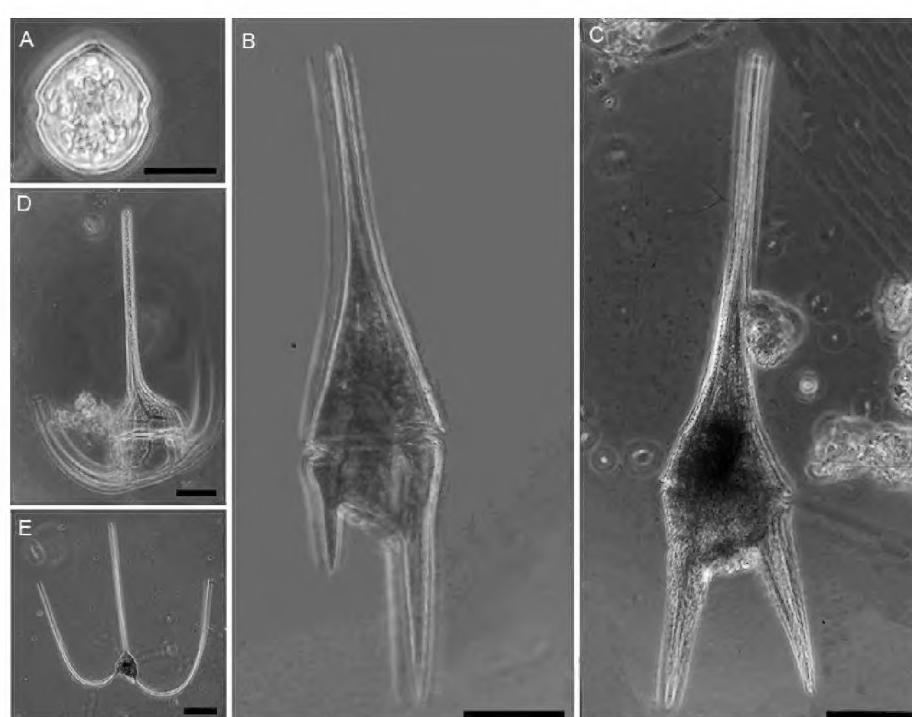


Figure 2. Species of *Scrippsiella* and *Tripos*. **A.** *Scrippsiella* cf. *acuminata* **B.** *Tripos furca*. **C.** *Tripos hircus*. **D.** *Tripos muelleri*. **E.** *Tripos trichoceros*. Scale bars A = 10 µm; B = 20 µm; C, E = 30 µm, D = 50 µm.

Epitheca conical with convex margins and a short apical process, hypotheca rounded, cingulum equatorial and slightly excavated. TL: 35 µm, TW: 20 µm ($n = 1$).

Taxonomic remarks. The only specimen observed is clearly assigned to *S. acuminata*-like cells due to its shape, size, and cytological features. However, due to its rarity in the samples we could not observe diacritical thecal features that accurately confirm its specific identity. *Scrippsiella acuminata* is widely distributed in the coastal regions of the world, usually identified as *Scrippsiella trochoidea* (Stein) Balech ex Loeblich III. However, Kretschmann et al. (2015) showed that *Peridinium acuminatum* Ehrenberg (the basionym of *S. acuminata*) and *S. trochoidea* are conspecific and considered *S. trochoidea* to be a later heterotypic synonym of the former.

Distribution in Brazil: coastal regions of Pará, Bahia, Espírito Santo, Rio de Janeiro, Santa Catarina and Rio Grande do Sul; cited as *S. trochoidea* (Flora do Brasil 2019).

Family Ceratiaceae Kofoed, 1907

Tripos furca (Ehrenberg) Gómez, 2013

Figure 2B

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, VII.2007 (HUESC 24078); Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, VII.2007 (HUESC 24078); Mixing Zone Station 3, 13°57'24"S, 038°59'38"W, V.2007 (HUESC 24072), IX.2006 (HUESC 24040); Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, XI.2006 (HUESC 24049), XII.2006 (HUESC 24053), II.2007 (HUESC 24061), III.2007 (HUESC 24065), V.2007 (HUESC 24073), VI.2007 (HUESC 24077), VII.2007 (HUESC 24081), VIII.2007 (HUESC 24085).

Narrow, long cell body, epitheca conical, gradually tapered into a cylindrical apical horn, cingulum excavated, two parallel antapical horns of variable length, the right antapical horn being smaller than the left one. TL: 162.5–177.5 µm (171.7 ± 8.04 µm), EL: 82.5–100

µm (92.8 ± 9.17 µm), CW: 30–37.5 µm (34.2 ± 3.82 µm), RAH: 30–42.5 µm (35.8 ± 6.29 µm), LAH: 70–80 µm (74.2 ± 5.20 µm) ($n = 15$).

Distribution in Brazil: widely distributed along the Brazilian coastal region (Flora do Brasil 2019).

Tripos hircus (Schröder) Gomez, 2013

Figure 2C

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, IX.2006 (HUESC 24039), X.2006 (HUESC 24042), XI.2006 (HUESC 24046), I.2007 (HUESC 24054), II.2007 (HUESC 24058), III.2007 (HUESC 24062), IV.2007 (HUESC 24066), V.2007 (HUESC 24070), VI.2007 (HUESC 24074), VII.2007 (HUESC 24078), VIII.2007 (HUESC 24082); Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, X.2006 (HUESC 24043), XI.2006 (HUESC 24047), XII.2006 (HUESC 24051), I.2007 (HUESC 24055), II.2007 (HUESC 24059), III.2007 (HUESC 24063), IV.2007 (HUESC 24067), V.2007 (HUESC 24071), VI.2007 (HUESC 24075), VII.2007 (HUESC 24079), VIII.2007 (HUESC 24083); Mixing Zone Station 3, 13°57'24"S, 038°59'38"W, IX.2006 (HUESC 24040), X.2006 (HUESC 24044), XI.2006 (HUESC 24048), XII.2006 (HUESC 24052), I.2007 (HUESC 24056), III.2007 (HUESC 24064), IV.2007 (HUESC 24068), V.2007 (HUESC 24072), VI.2007 (HUESC 24076), VII.2007 (HUESC 24080), VIII.2007 (HUESC 24084); Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, IX.2006 (HUESC 24041), X.2006 (HUESC 24045), XI.2006 (HUESC 24049), III.2007 (HUESC 24065), IV.2007 (HUESC 24069), V.2007 (HUESC 24073), VI.2007 (HUESC 24077), VII.2007 (HUESC 24081), VIII.2007 (HUESC 24085).

Narrow, long cell body, epitheca conical, gradually tapered into a cylindrical apical horn, cingulum excavated, two long divergent antapical horns of almost equal size. TL: 135–262.5 µm (221.7 ± 40.4 µm), EL: 80–167.5 µm (139.1 ± 30.7 µm), CW: 25–62.5 µm (41.4 ± 8.6 µm), RAH: 20–55 µm (44.8 ± 11.6 µm), LAH: 25–62.5 µm (54.8 ± 8.5 µm) ($n = 68$).

Distribution in Brazil: widely distributed along the Brazilian coastal region (Flora do Brasil 2019).

Tripos muelleri Bory, 1827

Figure 2D

Brazil, estuary of Maraú River: Mixing Zone Station 3, 13°57'24"S, 038°59'38"W, III.2007 (HUESC 24064); Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, XI.2006 (HUESC 24049), II.2007 (HUESC 24061), III.2007 (HUESC 24065), VII.2007 (HUESC 24081).

Large cell, asymmetrical triangular epitheca abruptly tapered into a straight and cylindrical apical horn, cingulum excavated, hypotheca with two well-developed antapical horns directed anteriorly, almost parallel to the apical horn, the right antapical horn is closer to the hypotheca than the left one. TL: 200–250 µm (227.75 ± 18.20 µm), EL: 192.5–200 µm (182.5 ± 12.08 µm), CW: 60–75 µm (67.75 ± 5.06 µm), RAH: 60–125 µm ($84.75 \pm$

17.73 µm), LAH: 87.5–132.5 µm (105 ± 15.5 µm), AH: 117.5–162.5 µm (140 ± 14.95 µm), HL: 35–50 µm (40.5 ± 5.63 µm) ($n = 5$).

Distribution in Brazil: widely distributed along the Brazilian coastal region; cited as *Ceratium tripos* (Müller) Nitzsch (Flora do Brasil 2019).

Tripos trichoceros (Ehrenberg) Gómez, 2013

Figure 2E

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, IX.2006 (HUESC 24039), I.2007 (HUESC 24054), VII.2007 (HUESC 24078); Mixing Zone Station 2, 14°04'52"S, 38°59'12"W, XI.2006 (HUESC 24047), XII.2006 (HUESC 24051), III.2007 (HUESC 24063), VI.2007 (HUESC 24075), VII.2007 (HUESC 24079); Mixing Zone Station 3, 13°57'24"S, 38°59'38"W, IX.2006 (HUESC 24040), X.2006 (HUESC 24044), XI.2006 (HUESC 24048), XII.2006 (HUESC 24052), III.2007 (HUESC 24064), IV.2007 (HUESC 24068), V.2007 (HUESC 24072), VI.2007 (HUESC 24076), VII.2007 (HUESC 24080); Coastal Zone Station 4, 13°54'56"S, 38°58'57"W, IX.2006 (HUESC 24041), X.2006 (HUESC 24045), XI.2006 (HUESC 24049), XII.2006 (HUESC 24053), II.2007 (HUESC 24061), III.2007 (HUESC 24065), IV.2007 (HUESC 24069), VII.2007 (HUESC 24081).

Small cell body with long projections, asymmetrical triangular epitheca abruptly tapered into a long, straight and thin apical horn, cingulum excavated, hypotheca with two well-developed curved antapical horns directed anteriorly, divergent from the apical horn. TL: 187.5–287.5 µm (232.5 ± 45.60 µm), EL: 100–250 µm (182.5 ± 55.87 µm), CW: 37.5–50 µm (42.5 ± 5.30 µm), RAH: 100–237.5 µm (166 ± 38.91 µm), LAH: 87.5–225 µm (157 ± 39.85 µm), AH: 82.5–237.5 µm (165.5 ± 56.61 µm), HL: 15–30 µm (22 ± 5.70 µm) ($n = 26$).

Distribution in Brazil: widely distributed along the Brazilian coastal region; cited as *Ceratium trichoceros* (Ehrenberg) Kofoid (Flora do Brasil 2019).

Family Dinophysiaceae Stein, 1883

Dinophysis caudata Saville-Kent 1881

Figure 3A, B

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, IX.2006 (HUESC 24039), X.2006 (HUESC 24042), XI.2006 (HUESC 24046), VI.2007 (HUESC 24074); Mixing Zone Station 2, 14°04'52"S, 38°59'12"W, X.2006 (HUESC 24043), II.2007 (HUESC 24059), VI.2007 (HUESC 24075), VII.2007 (HUESC 24079), VIII.2007 (HUESC 24083); Mixing Zone Station 3, 13°57'24"S, 38°59'38"W, IX.2006 (HUESC 24040), X.2006 (HUESC 24044), XI.2006 (HUESC 24048), XII.2006 (HUESC 24052), I.2007 (HUESC 24056), II.2007 (HUESC 24060), III.2007 (HUESC 24064), IV.2007 (HUESC 24068), V.2007 (HUESC 24072), VI.2007 (HUESC 24076), VII.2007 (HUESC 24080), Coastal Zone Station 4, 13°54'56"S,



Figure 3. Species of *Dinophysis*, *Metadinophysis*, and *Ornithocercus*. **A, B.** *Dinophysis caudata*. **A.** Typical form. **B.** Small form. **C.** *Metadinophysis cf. sinensis*. **D.** *Ornithocercus magnificus*. Scale bars: B, C = 10 µm, A, D = 20 µm.

038°58'57"W, IX.2006 (HUESC 24041), X.2006 (HUESC 24045), I.2007 (HUESC 24057), II.2007 (HUESC 24061), III.2007 (HUESC 24065), VI.2007 (HUESC 24077), VIII.2007 (HUESC 24085).

Cells with reduced epitheca and large hypotheca, prolonged by a well-defined caudal appendage posteriorly—ventrally oriented, in lateral view, dorsal margin of cell convex and ventral margin usually straight, short right sulcal list and long left one, supported by three well-developed ribs.

Taxonomic remarks: many specimens observed in this study are similar to the species described as *Dinophysis diegensis* Kofoid; however, these small cells are currently considered as an intermediate stage of *D. caudata* (Reguera et al. 2007).

Typical *D. caudata* cells: CL: 37.5–90.0 µm (61.2 ± 20.6 µm), TL: 55–100 µm (87.7 ± 19.9 µm), CW: 25.0–62.5 µm (39.2 ± 11.3 µm), TW: 30–75 µm (57.5 ± 14.3 µm), R1–R2: 12.5–27.5 µm (20.6 ± 4.6 µm), R2–R3: 10–25 µm (16.9 ± 4.9 µm) ($n = 27$).

Small forms (*D. diegensis*-like): CL: 32.5–37.5 µm (35 ± 2.5 µm), TL: 40–50 µm (46.7 ± 5.77 µm), CW: 17.5–22.5 µm (20 ± 2.5 µm), TW: 25–30 µm (26.7 ± 2.89 µm), R1–R2: 10–15 µm (11.7 ± 2.89 µm), R2–R3: 7.5–12.5 µm (9.2 ± 2.89 µm) ($n = 5$).

Distribution in Brazil: widely distributed on the eastern, southeastern, and southeastern coasts of Brazil (Flora do Brasil 2019).

Metadinophysis cf. sinensis Nie & Wang, 1941

Figure 3C

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, X.2006 (HUESC 24042), XI.2006 (HUESC 24046); Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, X.2006 (HUESC 24043).

Small to medium-sized cells, small epitheca, and laterally flattened hypotheca prolonged by a acute extension in the antapex. CL: 36.46–45 µm (39.84 ± 4.54 µm), TL: 42.23–48.23 µm (44.27 ± 3.43 µm), CW: 19.76–24.11 µm (21.29 ± 2.45 µm), TW: 24.11–29.41 µm (25.97 ± 2.98 µm), R1–R2: 4.38–5.88 µm (5.08 ± 0.75 mm), R2–R3: 9.76–11.76 µm (11.09 ± 1.15 µm) ($n = 3$)

Taxonomic remarks: this species is characterized by a slight slant of the epitheca and cingulum and by a flexion of the sagittal plane (the one containing the dorsoventral axis). As we do not show accurately all diacritical features of this species due its rarity in the samples, we prefer to treat it as *Metadinophysis cf. sinensis*.

Distribution in Brazil: *Metadinophysis sinensis* has been reported to Camamu Bay (Affe et al. in press).

Ornithocercus magnificus Stein, 1883

Figure 3D

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, II.2007 (HUESC 24058).

Large cells, subcircular body in lateral view, with epitheca very reduced, cingular lists well-developed and supported by rays and other short segments, thecal surface ornamented by small pores and alveoli, left sulcal list extend from ventral to dorsal margin of the cell, with three well-marked lobes supported by five large ribs. CL: 37.5 µm, TL: 87.5 µm, CW: 42.5 µm, LT: 87.5 µm, ACL: 67.5 µm, PCL: 67.5 µm, LSL: 25 µm ($n = 1$).

Taxonomic remarks: this species can be distinguished from *O. thumii* (Schmidt) Kofoid & Skogsberg by its smaller size and the structure of the lists, which are more developed in *O. thumii* (Balech 1988).

Distribution in Brazil: coastal regions of Amapá, Ceará, and Rio Grande do Norte; along the eastern, southeastern, and southern coasts (Flora do Brasil 2019).

Family Gonyaulacaceae Lindemann, 1928

Amylax diacantha Meunier, 1919

Figure 4A, B

Brazil, Estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, IX.2006 (HUESC 24039); Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, XI.2006 (HUESC 24047).

Cell pentagonal, epitheca conical gradually reduced in a short apical horn, hypotheca trapezoid with two divergent antapical spines, surface of thecal plates reticulate with longitudinal ridges, cingulum descending, no overlapping. TL: 30.5 µm; CW: 19.4 µm ($n = 2$).

Taxonomic remarks: *Amylax diacantha*, when transferred to the genus *Gonyaulax*, was renamed *Gonyaulax verior* Sournia (Sournia 1973), as the combination

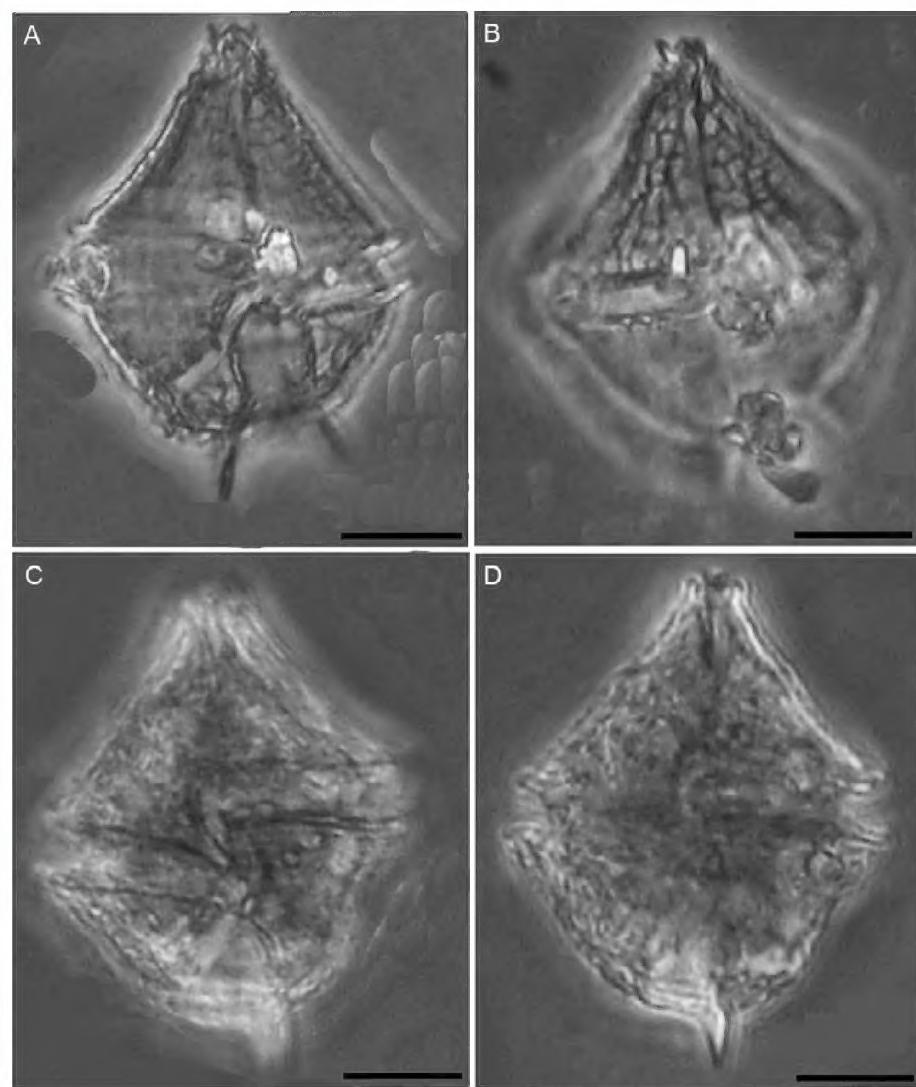


Figure 4. Species of *Amylax* and *Gonyaulax*. **A, B.** *Amylax diacantha* specimen in ventral view A and specimen in dorsal view B. **C, D.** *Gonyaulax spinifera*, specimen in ventral view (C) and specimen in dorsal view (D). Scale bars = 10 µm.

Gonyaluax diacantha Athanassopontos 1931 for another taxon had priority under the rules of International Code of Nomenclature for Algae, Fungi, and Plants (ICN). Morphologically, *Amylax diacantha* (Po, 4', 2a, 6", 6c, 7s, 6", 1p, 1'') does not fit into the typical *Gonyaulax* tabulation (Po, 3', 2a, 6", 6c, 7s, 6", 1p, 1''). Furthermore, that species shows marginal pore in the plate 1' near 4' and 2a and the orientation of sulcal plates are of the L-type (following Fensome et al. 1993), so it should not be attributed to the genus *Gonyaulax* (Matsuoka et al. 1988; Zonneveld and Dale 1994). Phylogenetically, the species is closer to *Lingulodinium* Wall and less related to *Gonyaulax* sensu stricto (Koike and Takishita 2008). Therefore, the combination *A. diacantha* should be preferred for this taxon and the relationships between *Amylax* and *Lingulodinium* should be reviewed.

Distribution in Brazil: coastal regions of Bahia (Affe 2012; Santana 2012), São Paulo, Rio de Janeiro and Rio Grande do Sul; cited as *Gonyaulax verior* (Flora do Brasil 2019).

Gonyaulax spinifera (Claparède & Lachmann) Diesing, 1866

Figure 4C, D

Brazil, estuary of Maraú River: Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, XI.2006 (HUESC 24047), I.2007 (HUESC 24054); Mixing Zone Station 3, 13°57'24"S, 038°59'38"W, XI.2006 (HUESC 24048), Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, X.2006 (HUESC 24045).

Rhomboïd cell, slightly longer than broad,

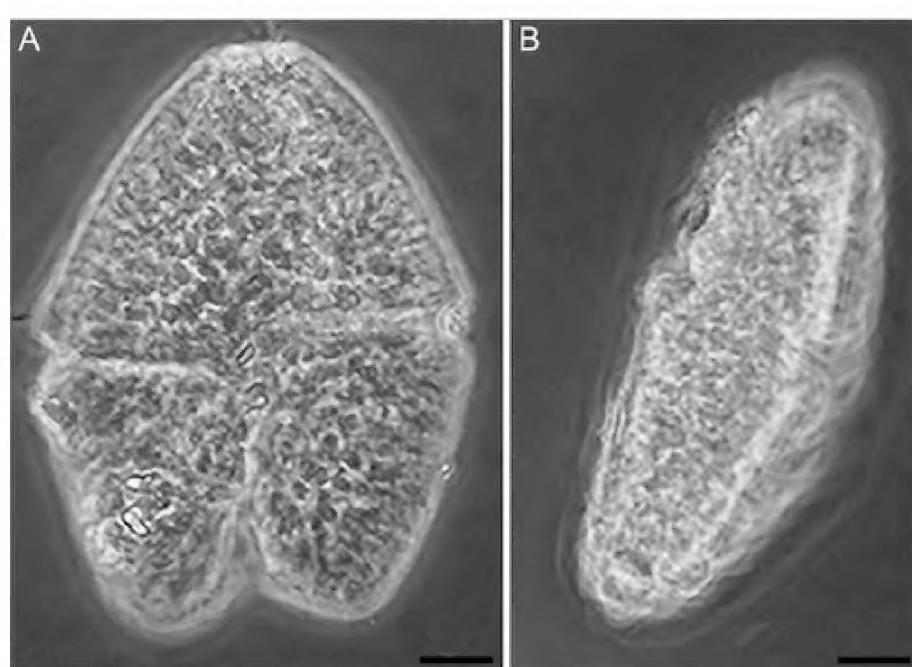


Figure 5. *Akashiwo sanguinea*. **A.** Specimen in ventral view. **B.** Specimen in lateral view. Scale bars = 10 μ m.

epitheca conical gradually reduced in a short apical horn, hypotheca with variable number of antapical spines with lateral lists, cingulum wide, excavated, descending, with marked overlapping and displaced 2 \times cingulum width. TL: 27.5–40 μ m (33.8 \pm 5.9 μ m), CW: 25–27.2 μ m (26.05 \pm 1.22 μ m) (n = 4).

Distribution in Brazil: coastal regions of Pará, Rio Grande do Norte, Rio de Janeiro, Santa Catarina, and Rio Grande do Sul (Flora do Brasil 2019), Bahia (Affe et al. 2018).

Family Gymnodiniaceae Lankester, 1885

***Akashiwo sanguinea* (Hirasaka) Hansen & Moestrup, 2000**

Figure 5A, B

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 39°02'48"W, III.2007 (HUESC 24062).

Naked ovoid cell with median cingulum and bilobed hypocone, in lateral view, cells dorsiventrally flattened with the dorsal side convex and ventral one flat, cingulum descending, displaced by 1 \times cingulum width, sulcus narrow, reaching antapex. TL: 69 μ m, CW: 50 μ m, EL: 33.3 μ m, HL: 36 μ m, CT: 27.7 μ m (n = 1).

Distribution to Brazil: coastal regions of Bahia, Rio Grande do Norte, Espírito Santo, Rio de Janeiro, Santa Catarina, and Rio Grande do Sul; sometimes forming blooms (Flora do Brasil 2019).

Family Prorocentraceae Stein, 1883

***Prorocentrum micans* Ehrenberg, 1833**

Figure 6A

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, III.2007 (HUESC 24062), IV.2007 (HUESC 24066), VI.2007 (HUESC 24074), VII.2007 (HUESC 24078), VIII.2007 (HUESC 24082); Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, XI.2006 (HUESC 24047), I.2007 (HUESC 24055), II.2007 (HUESC 24059), III.2007 (HUESC 24063), VI.2007 (HUESC 24075), VII.2007 (HUESC 24079), VIII.2007 (HUESC 24083); Mixing Zone Station 3, 13°57'24"S, 038°59'

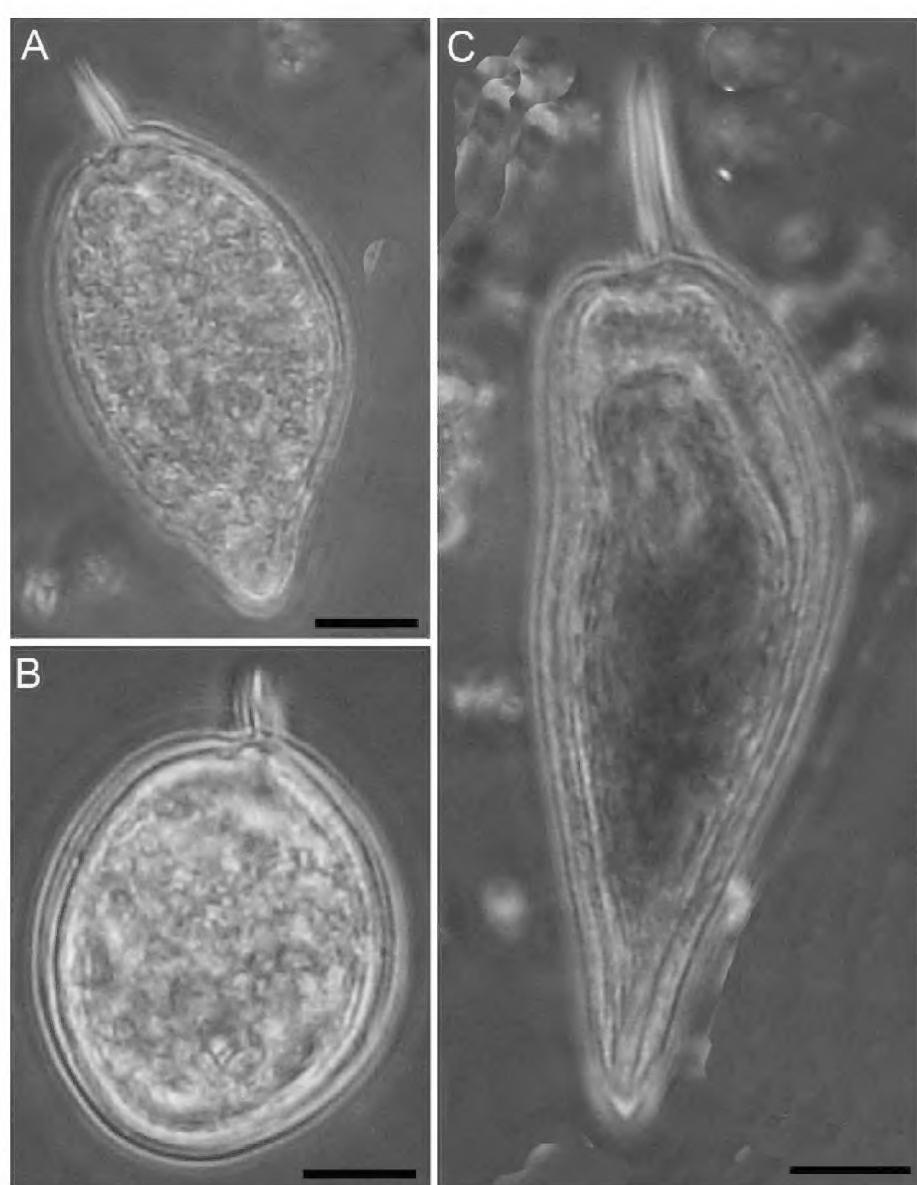


Figure 6. Species of *Prorocentrum*. **A.** *P. micans*. **B.** *P. scutellum*. **C.** *P. gracile*. Scale bars = 10 μ m.

38"W, II.2007 (HUESC 24060), III.2007 (HUESC 24064), IV.2007 (HUESC 24068), V.2007 (HUESC 24072), VI.2007 (HUESC 24076), VII.2007 (HUESC 24080), VIII.2007 (HUESC 24084); Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, X.2006 (HUESC 24045), I.2007 (HUESC 24057), II.2007 (HUESC 24061), III.2007 (HUESC 24065), IV.2007 (HUESC 24069), V.2007 (HUESC 24073), VI.2007 (HUESC 24077).

Medium-sized, oval cell with asymmetrical sides, larger diameter in the central portion of the valve; antapex attenuated; one anterior, winged, straight spine. CL: 40–50 μ m (46.1 \pm 3.6 μ m), TL: 50–60 μ m (54.8 \pm 3.8 μ m), CW: 25–30 μ m (27.4 \pm 2.2 μ m) (n = 26).

Distribution in Brazil: coastal regions of Pará, Maranhão, Rio Grande do Norte, Pernambuco, and Bahia; along the southeastern and southern coasts (Flora do Brasil 2019).

***Prorocentrum scutellum* Schröder, 1900**

Figure 6B

Brazil, estuary of Maraú River: Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, X.2006 (HUESC 24045)

Cell subcircular, larger diameter in the central portion of the valve; antapex rounded; one anterior winged spine curved towards the dorsal side. CL: 31.8 μ m, CW: 27.3 μ m, SL: 2.5 μ m (n = 1)

Distribution in Brazil: coastal regions of Amapá, Pará, Rio Grande do Norte, Bahia, Espírito Santo, Rio de Janeiro, Santa Catarina, and Rio Grande do Sul (Flora do Brasil 2019).

***Prorocentrum gracile* Schütt**

Figure 6C

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, IX.2006 (HUESC 24039), X.2006 (HUESC 24042), III.2007 (HUESC 24062), VII.2007 (HUESC 24078), VIII.2007 (HUESC 24082); Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, XI.2006 (HUESC 24047), I.2007 (HUESC 24055), II.2007 (HUESC 24059), III.2007 (HUESC 24063), V.2007 (HUESC 24071), VI.2007 (HUESC 24075), VII.2007 (HUESC 24079), VIII.2007 (HUESC 24083); Mixing Zone Station 3, 13°57'24"S, 038°59'38"W, IX.2006 (HUESC 24040), XI.2006 (HUESC 24048), XII.2006 (HUESC 24052), I.2007 (HUESC 24056), II.2007 (HUESC 24060), III.2007 (HUESC 24064), IV.2007 (HUESC 24068), V.2007 (HUESC 24072), VI.2007 (HUESC 24076), VII.2007 (HUESC 24080), VIII.2007 (HUESC 24084); Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, X.2006 (HUESC 24045), II.2007 (HUESC 24061), IV.2007 (HUESC 24069), VI.2007 (HUESC 24077), VII.2007 (HUESC 24081), VIII.2007 (HUESC 24085).

Cell elongated, piriform, with asymmetrical sides; one margin convex and other slightly sigmoid; antapex pointed; one long, winged anterior spine. CL: 40–72.5 µm (58.9 ± 12.1 µm), TL: 55–90 µm (75.8 ± 13.7 µm), CW: 20–25 µm (22.4 ± 2.1 µm) ($n = 29$).

Distribution in Brazil: coastal regions of Amapá, Pará, Rio Grande do Norte, and Pernambuco; along the eastern, southeastern, and southern coasts (Flora do Brasil 2019).

Family Protoperidiniaceae Balech, 1988

***Protoperidinium cf. argentinense* Balech, 1979**

Figure 7A, B

Brazil, estuary of Maraú River: Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, I.2007 (HUESC 24055).

Epitheca small, conical, with sinuous sides; tabulation ortho-hexa; plate 1' convex, with short proximal sides and long distal sides almost parallel in the central part; anterior intercalary plates almost equal in size, with 2a hexagonal and 1a and 3a pentagonal. CW: 29.5 µm, EL: 19.5 µm ($n = 1$).

Taxonomic remarks: the only epitheca observed in this study is similar to *P. cf. argentinense*, from the Gulf of Mexico, in having three intercalary plates (Okolodkov 2008). This feature makes it distinct of *P. argentinense*, as originally described by Balech (1979, 1988), which has only two unequal intercalary plates. Analysis of more individuals is required for accurate identification.

Distribution in Brazil: this species has never been cited for Brazil.

***Protoperidinium conicum* (Gran) Balech, 1974**

Figure 7 C, D

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, X.2006 (HUESC 24042), III.2007 (HUESC 24062); Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, XI.2006 (HUESC 24047), II.2007

(HUESC 24059); Mixing Zone Station 3, 13°57'24"S, 038°59'38"W, VI.2007 (HUESC 24076); Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, X.2006 (HUESC 24045).

Cell pentagonal, dorsiventrally flattened; epitheca conical, without apical horn; cingulum excavated, circular, without displacement; tabulation ortho-hexa, plate 1' diamond-shaped, as long as wide and plate 2a trapezoidal; hypotheca with short antiapical horns ended by short spines. TL: 80 µm, CW: 100 µm ($n = 1$).

Distribution in Brazil: coastal regions of Amapá, Pará; along the eastern, southeastern, and southern coasts (Flora do Brasil 2019).

***Protoperinium ovum* (Schiller) Balech, 1974**

Figure 7E–H

Brazil, Estuary of Maraú River: Mixing Zone Station 3, 13°57'24"S, 038°59'38"W, III.2007 (HUESC 24064), VIII.2007 (HUESC 24084); Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, X.2006 (HUESC 24045), XI.2006 (HUESC 24049), XII.2006 (HUESC 24053), I.2007 (HUESC 24057), II.2007 (HUESC 24061).

Ovoid cells with a small marked apical horn; cingulum ascending, not excavated; tabulation para-hexa; two long antiapical spines slightly divergent and oriented ventrally, with a well-developed left sulcal list. TL: 38.6–57.5 (45.7 ± 10.3 µm), TW: 27.2–52.5 µm (35.7 ± 14.6 µm), EL: 9.1–15.9 µm (13.3 ± 3.7 µm), HL: 10–37.5 µm (20.4 ± 14.9 µm) ($n = 3$).

Distribution in Brazil: coastal regions of Bahia (Santana 2012), Santa Catarina, and Rio grande do Sul (Flora do Brasil 2019).

***Protoperidinium cf. subinerme* (Paulsen) Loeblich III, 1969**

Figure 8A–C

Brazil, estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, I.2007 (HUESC 24054); Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, I.2007 (HUESC 24055); Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, X.2006 (HUESC 24045).

Small, pentagonal cell, epitheca conical projecting a short apical pore; hypotheca conical, with two diminute antiapical spines; distance between antiapical spines 2× cingulum width; cingulum equatorial, strongly excavated with a narrow cingular list; tabulation ortho-hexa; epithelial tabulation asymmetric, with plates 3', 2', and 4' shifted to left side, plate 1' diamond-shaped, distal sides markedly longer (1.3 times) than proximal sides; plate 1a smaller than plate 3a and plate 2a hexagonal and as wide as plate 4", thecal surface ornated by weak punctuate polygonal mesh. CL: 33.3 µm, CW: 38.1 µm, EL: 12.3 µm, HL: 15.2 µm, Cw: 5.6 µm ($n = 1$).

Taxonomic remarks: The specimen from Maraú estuary resembles the species illustrated by Abé (1981: 365–368, fig. 54) as *Peridinium subinerme*. However, our specimen is smaller than shown by Abé (1981; CL= 47–50 µm, CW=50–55 µm) and the distal sides of plate 1'

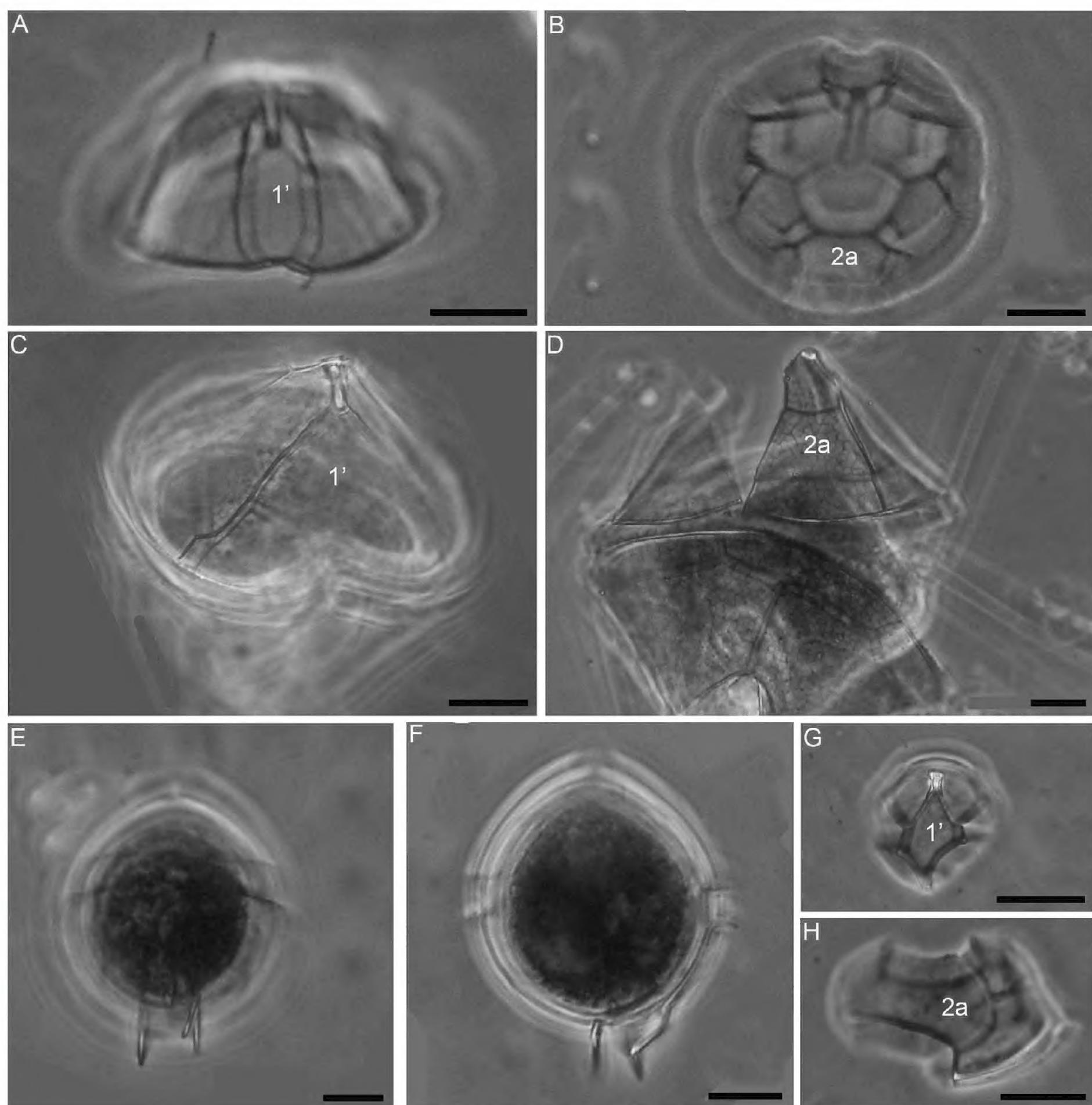


Figure 7. Species of *Protoperidinium*. **A, B.** *P. cf. argentinense*. **A.** Epitheca in ventral view. **B.** Epitheca in apical view. **C, D.** *P. conicum*. **C.** Specimen in ventral view. **D.** Specimen in dorsal view. **E–H.** *P. ovum*: (E) ventral view; (F) lateral view; (G) part of ventral epitheca; (H) part of dorsal epitheca. Scale bars = 10 µm.

are markedly larger than the proximal sides.

Distribution in Brazil: coastal regions of Amapá, Rio Grande do Norte, and Santa Catarina (Flora do Brasil 2019). This taxon has never been reported in the state of Bahia.

Protoperidinium venustum (Matzenauer) Balech, 1974

Figure 8D, E

Brazil, estuary of Maraú River: Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, I.2007 (HUESC 24055).

Cell longitudinally elongate, dorsiventrally flattened, with a conical apical horn and two pointed antapical horns; cingulum descending not excavate; tabulation ortho-quadrata; plate 1' with distal sides smaller than proximal sides; plate 2a small, wider than long; sulcus

with a small projection towards the epitheca. TL: 85–96 (89.5 ± 5.8 µm), CW: 62.5–69 (65.5 ± 3.3 µm) ($n = 3$).

Distribution in Brazil: coastal regions of Pernambuco and Rio Grande do Sul (Flora do Brasil 2019). This is the first record for Bahia.

Family Pyrophacaceae Lindemann, 1928

Pyrophacus horologium Stein, 1883

Figure 8F, G

Brazil, Estuary of Maraú River: River Zone Station 1, 14°06'33"S, 039°02'48"W, X.2006 (HUESC 24042), XI.2006 (HUESC 24046), I.2007 (HUESC 24054); Mixing Zone Station 2, 14°04'52"S, 038°59'12"W, X.2006 (HUESC 24043), XI.2006 (HUESC 24047), I.2007 (HUESC 24055), II.2007 (HUESC 24059), III.2007

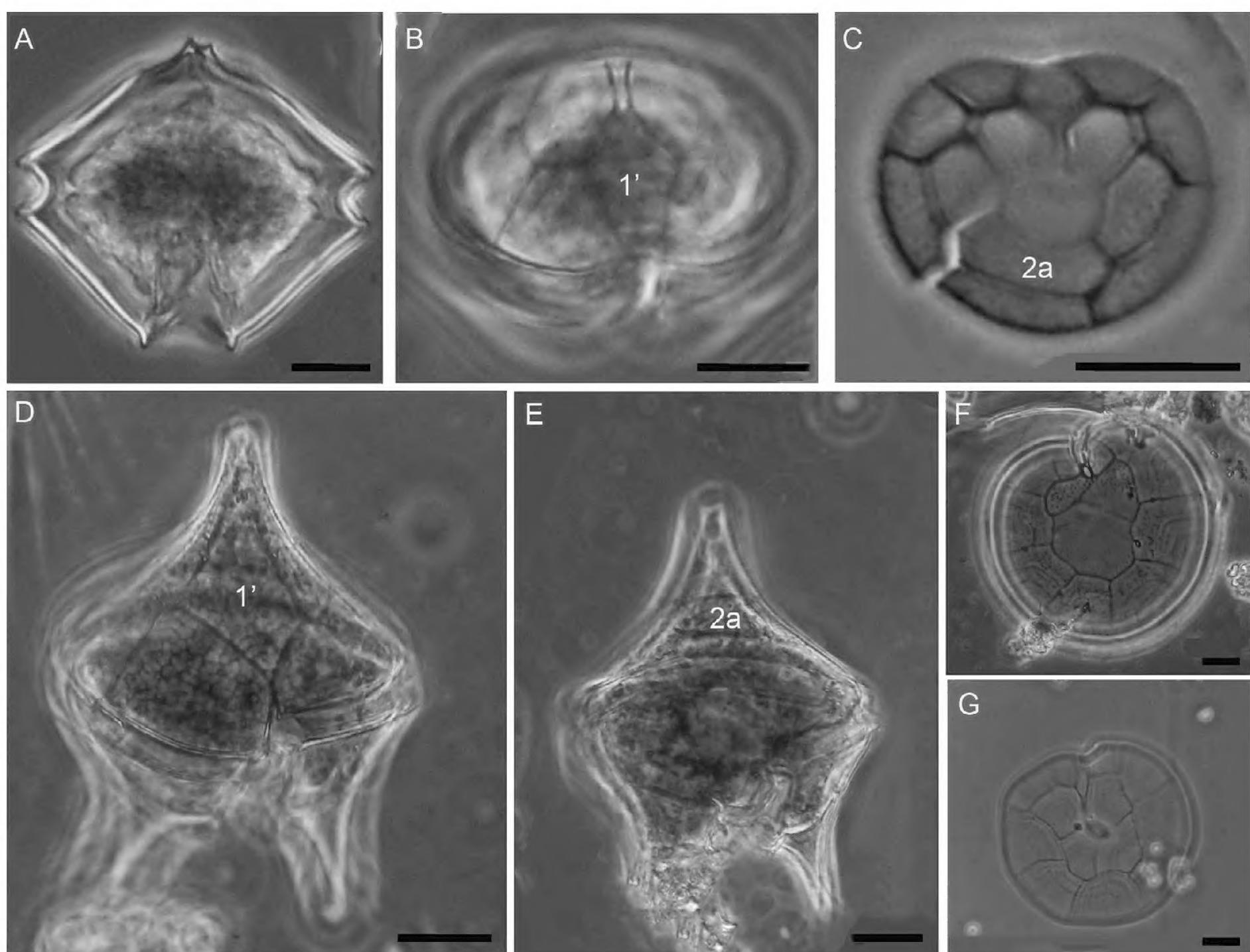


Figure 8. Species of *Protoperidinium* and *Pyrophacus*. **A–C.** *Protoperidinium* cf *subinerme*: (A) ventral view; (B) ventral view of epitheca; (C) epitheca in apical view. **D, E.** *Protoperidinium* *venustum*: (D) ventral view; (E) dorsal view. **F, G.** *Pyrophacus* *horologium*: (F) hypotheca; (G) epitheca. Scale bars: A–E = 10 µm; F, G = 20 µm.

(HUESC 24063); Mixing Zone Station 3, 13°57'24"S, 038°59'38"W, IX.2006 (HUESC 24040), X.2006 (HUESC 24044), XI.2006 (HUESC 24048), XII.2006 (HUESC 24052), I.2007 (HUESC 24056), III.2007 (HUESC 24064), IV.2007 (HUESC 24068), V.2007 (HUESC 24072); Coastal Zone Station 4, 13°54'56"S, 038°58'57"W, X.2006 (HUESC 24045), XII.2006 (HUESC 24053), I.2007 (HUESC 24057), II.2007 (HUESC 24061), IV.2007 (HUESC 24069).

Cells apically flattened, lenticular, showing typical apical pore; epitheca showing five apical and nine pre-cingular plates; hypotheca with nine post-cingular, three antapical, and one posterior intercalar plates. CW: 60–100 µm (71.9 ± 11.20 µm) ($n = 38$).

Distribution in Brazil: coastal regions of Pará; along the northeastern, eastern, southeastern and southern coasts (Flora do Brasil 2019).

Discussion

The most common species in this study were *Tripos hircus*, *Dinophysis caudata*, *Prorocentrum micans*, *P. gracile*, and *T. trichoceros* (Table 1). They were common throughout the study period in all stations in the estuary. These dinoflagellates are typically neritic or

estuarine and widely distributed in the world's oceans. They have a wide tolerance to variations in salinity and temperature (Steidinger and Tangen 1997). Many of the dinoflagellate species found in the Maraú River estuary are common in the adjacent coastal area (Flora do Brasil 2019). Moreover, the presence of typically marine species such as *Akashiwo sanguinea*, *Amylax diacantha*, and *Ornithocercus magnificus*, in the innermost portion of the estuary (RZ) suggests they are allochthonous in coastal waters and transported into the estuary by surface currents or tidal dispersion. The strong influence of a mass of tropical water along the coast of Bahia (Ekau and Knoppers 1999) results in the presence of typical tropical marine dinoflagellates in the estuary.

Among the 20 dinoflagellate species found, six are recognized in the literature as potentially harmful. These are *Scrippsiella acuminata* (if its identity is confirmed), *Prorocentrum micans* and *Tripos furca* (not toxicogenic species but their blooms can cause oxygen depletion in water, resulting in fish mortality; Faust and Gulledge 2002; Glibert et al. 2002; Hallegraeff 2003); *Dinophysis caudata* (produces okadaic acid and dinophysistoxins, causing diarrhetic shellfish poisoning in humans; Reguera et al. 2014); *Gonyaulax spinifera* (produces yessotoxin, causing ciguatera poisoning in humans

Table 1. Distribution and frequency of occurrence (FO) of dinoflagellates in the estuary of Maraú River, September 2006 to August 2007 (RZ: River Zone; MZ: Mixing Zone; CZ: Coastal Zone).

Species	Sep/06	Oct/06	Nov/06	Dec/06	Jan/07	Feb/07	Mar/07	Apr/07	May/07	Jun/07	Jul/07	Aug/07	FO
<i>Scrippsiella cf. acuminata</i>	—	—	—	—	MZ	—	—	—	—	—	—	—	2.8
<i>Triplos furca</i>	MZ	—	CZ	CZ	—	CZ	CZ	—	MZ, CZ	CZ	RZ, MZ, CZ	—	27.8
<i>Triplos hircus</i>	RZ, MZ, CZ	RZ, MZ, CZ	RZ, MZ, CZ	MZ	RZ, MZ	RZ, MZ	RZ, MZ, CZ	88.9					
<i>Triplos muelleri</i>	—	—	CZ	—	—	CZ	MZ, CZ	—	—	—	CZ	—	13.9
<i>Triplos trichoceros</i>	RZ, MZ, CZ	MZ, CZ	MZ, CZ	MZ, CZ	RZ	CZ	MZ, CZ	MZ, CZ	MZ	MZ	RZ, MZ, CZ	—	47.2
<i>Dinophysis caudata</i>	RZ, MZ, CZ	RZ, MZ, CZ	RZ, MZ	MZ	MZ, CZ	MZ, CZ	MZ, CZ	MZ	RZ, MZ, CZ	MZ	MZ, CZ	—	61.1
<i>Metadinophysis cf. sinensis</i>	—	RZ, MZ	RZ	—	—	—	—	—	—	—	—	—	8.3
<i>Ornithocercus magnificus</i>	—	—	—	—	—	RZ	—	—	—	—	—	—	2.8
<i>Amylax diacantha</i>	RZ	—	MZ	—	—	—	—	—	—	—	—	—	5.6
<i>Gonyaulax spinifera</i>	—	CZ	MZ	—	MZ	—	—	—	—	—	—	—	8.3
<i>Akashiwo sanguinea</i>	—	—	—	—	—	—	RZ	—	—	—	—	—	2.8
<i>Prorocentrum micans</i>	—	CZ	MZ	—	MZ, CZ	MZ, CZ	RZ, MZ, CZ	RZ, MZ, CZ	MZ, CZ	RZ, MZ, CZ	RZ, MZ	RZ, MZ	58.3
<i>Prorocentrum scutellum</i>	—	CZ	—	—	—	—	—	—	—	—	—	—	2.8
<i>Prorocentrum gracile</i>	RZ, MZ	RZ, CZ	MZ	MZ	MZ	MZ, CZ	RZ, MZ	MZ, CZ	MZ	MZ, CZ	RZ, MZ, CZ	RZ, MZ, CZ	55.6
<i>Protoperidinium cf. argentinense</i>	—	—	—	—	MZ	—	—	—	—	—	—	—	2.8
<i>Protoperidinium conicum</i>	—	RZ, CZ	MZ	—	—	MZ	RZ	—	—	MZ	—	—	16.8
<i>Protoperidinium ovum</i>	—	CZ	CZ	CZ	CZ	CZ	MZ	—	—	—	—	MZ	19.4
<i>Protoperidinium cf. subinerme</i>	—	—	CZ	—	RZ, MZ	—	—	—	—	—	—	—	8.3
<i>Protoperidinium venustum</i>	—	—	—	—	MZ	—	—	—	—	—	—	—	2.8
<i>Pyrophyacus horologium</i>	—	RZ, MZ, CZ	RZ, MZ	MZ, CZ	RZ, MZ, CZ	MZ, CZ	MZ	MZ, CZ	MZ	—	—	—	44.5

eating contaminated reef fishes; Rhodes et al. 2006); and *Akashiwo sanguinea* (bloom-forming dinoflagellate whose toxin can lead to mass killing of marine animals; Jessup et al. 2009; Xu et al. 2017). Harmful algal blooms in estuaries can lead to many ecological, economic, and public health losses (Hallegraef 2003). In Camamu Bay, shellfish farming activity has been increasing in recent years, so further studies are recommended on the distribution and dynamics of these potentially harmful species, as well as monitoring for the detection of blooms (Affe 2012; Santana 2012).

One species, *Protoperidinium venustum*, are new occurrences for Bahia. In addition, it is necessary to confirm the identity of *Protoperidinium cf. subinerme*, which has not been previously reported from Bahia, and *Metadinophysis cf. sinensis* and *Protoperidinium cf. argentinense*, which have not been recorded previously from Brazil. Eight species are newly reported from Camamu Bay, which brings the total number of dinoflagellate species in the region to 40. This demonstrates that the dinoflagellate flora and its distribution in estuaries and along coastal regions of Bahia is still underestimated.

Acknowledgements

We thank FINEP for the financing of the project “Biogeography, diseases and implantation of oysters and sururu cultures in the Bay of Camamu, BA” (agreement no. 01.0289), in which this work forms part, and the Post-graduate Program in Tropical Aquatic Systems for the infrastructure and CAPES for the granting of the master’s degree of the first author. We are grateful to Dr Michael Guiry for valuable assistance on nomenclatural issues. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES), finance code 001.

Authors’ Contributions

CCSN: sampling, data processing, data analysis, writing; SMMSR: sampling, taxonomic review, writing, English review; KPC: taxonomic review, writing, English review

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